GEOGRAPHIC VARIATION IN BIOMETRIC CHARACTERS OF *PEGUSA LASCARIS* (SOLEIDAE) FROM IBERIAN WATERS

by

Isabel AFONSO-DIAS, Catarina REIS & J. Pedro ANDRADE (1)

ABSTRACT. - Meristic counts and morphometric measurements were carried out on fresh sand sole *Pegusa lascaris* (Risso, 1810) obtained from commercial landings in Iberian waters: Gulf of Cadiz, Algarve (South of Portugal) and Porto (North of Portugal). Three meristic and nine morphometric characters were examined for geographic variation. The Kruskal-Wallis test indicated a significant difference at 5% level of confidence in the meristic counts among the three localities. A principal component analysis was performed to analyse the morphometric variables. The results showed that around 84% of the total variance was explained by the three first components. All variables were highly scored with the first PC, except the pectoral and pre-anal lengths and minimum height (0.797, 0.825 and 0.794, respectively). Linear nested models were used to estimate the allometric relationships between the morphometric variables and to assess sex and geographic effects in the estimated parameters. The F-test used to test the equality of the regression parameters showed, in general, a significant sex and/or geographic effect ($p < 0.05$), except for the relationship between total length and pectoral length. These results clearly demonstrated geographic variation between the morphometric characters of sand sole in Iberian waters.

RÉSUMÉ. - Variations géographiques dans les caractéristiques biométriques de *Pegusa lascaris* des eaux Ibériques.

Des comptes méristiques et des mesures morphométriques ont été effectuées sur des individus frais de *Pegusa lascaris* (Risso, 1810), obtenus à partir des captures commerciales dans la Péninsule Ibérique, Golfe de Cadiz, Algarve (Sud du Portugal) et Porto (Nord du Portugal). Trois caractères méristiques et neuf morphométriques ont été étudiés pour détecter des variations géographiques. Le test de Kruskal-Wallis indique une différence significative de 5% pour les valeurs méristiques dans les trois localités. Une analyse en composantes principales a été realisée pour analyser les variables morphométriques. Le résultat indique que environ 84% du total de la variance est expliqué par les trois premieres composantes. Toutes les variables sont corrélées avec la première composante principale, sauf la longueur de la nageoire pectorale, la distance pré-anale et la hauteur minimale (0,797 ; 0,825 et 0,794, respectivement). Des modèles lineaires groupés ("nested") ont été utilisés pour estimer les relations allométriques entre les variables morphométriques et étudier les effets du sexe et de la répartition géographique sur les paramètres étudiés. Le test F utilisé pour montrer l'égalité des paramètres de la régression indique, en général, une variation en fonction du sexe et/ou de la répartition géographique qui est significative ($p < 0,05$), sauf pour la relation entre la longueur totale et la distance pré-anale. Ces résultats montrent que les caractères morphométriques de la sole pole des eaux Ibériques présentent des variations géographiques.

Key words. - Soleidae - *Pegusa lascaris* - ANE - Portugal - Meristic - Morphometry - Allometry.

The sand sole (*Pegusa lascaris*) has a very wide distribution in the North Eastern Atlantic waters. According to Whitehead *et al*. (1986), this species can be found on gravel, sand and muddy sand, from the southern part of the North Sea, southward from Scotland, to South Africa. It also occurs in Mediterranean waters and in the Adriatic Sea. The bathymetric distribution of this fish extends from about 5 to 350 m. However, it is more commonly found in shallow waters from 20 to 50 m (Whitehead *et al*., 1986).

This sole is mainly captured by the artisanal fleet with shellfish dredge, trammel and gill nets. Although there is no target fishery, in 1997 this species accounted for approximately 6% of the 219 tonnes of Soleidae landed in Algarve (DGPA, unpubl. data).

Despite the economic importance of this species, there is few biological information published regarding its biology. Even in other regions, this species did not receive much attention. Exceptions made with the study by Gaertner (1982) who used morphometric characters and meristic counts to differentiate two varieties of the same species of sand sole in the Bay of Douarnenez, France.

Although there is some improvement in the number of studies on the biometry of Soleidae due to the interest in their taxonomy (Ben-Tuvia, 1990; Desoutter, 1994; Desoutter, 1997), the number of papers published on this subject, regarding population differences both intra and inter specific, are still very scarce.

This study aims to contribute to a better knowledge of the biometry of the sand sole, by assessing the morphometric and meristic differences between specimens collected in three different localities, Porto, Algarve and Gulf of Cadiz.

(1) CCMar, FCMA - Universidade do Algarve, Campus de Gambelas, 8000-810 Faro, PORTUGAL. [idias@ualg.pt]

MATERIAL AND METHODS

Meristic counts

Meristic counts were carried out on fresh soles obtained from commercial landings in Iberian waters (Fig. 1). Approximately 100 individuals were sampled for meristic counts made on the dorsal, anal and pectoral fins (on the eyed side). The parameters estimated were median and count range of fin rays by fin. The Kolmogorov-Smirnov method (Zar, 1984) was used to assess any departure from normality. The Kruskal-Wallis test (Zar, 1984) was used to test geographic effect in the meristic counts (square root transformed).

Morphometric measurements

A total of 1713 fishes from Porto area, Algarve and Gulf of Cadiz, were sampled for morphometric measurements: total, standard and head length, dorsal, anal fins length, pre-anal length, maximum and minimum height (Fig. 2). Total length, standard length, dorsal and anal fin length were measured to the nearest 1 mm using a regular fish ruler. The other morphometric variables were determined using digital callipers to the nearest 0.1 mm. The morphometric characters were plotted against total length to check if they were adequately described by a straight-line relationship. The coefficient of determination, r^2, was estimated for each pair of variables as a measure of the strength of the straight-line relationship (Zar, 1984).

Principal component analysis (PCA) was used to investigate the geographic effect in the morphometric measurements (Manly, 1994). This analysis was performed in two ways; one considering the morphometric variables together for the three sources. In this case, the nine measurements were quite highly correlated, which was confirmed by estimating the correlation matrix between the variables. The objective was to verify if the analysis leads or not to the conclusion that most of the differences between individuals are a matter of size rather than origin of samples. The PCA was also performed with nine (measurements) times for three (sources) variables to check how the 27 variables were grouped with low or high values of each meaningful component.

Allometric relationships

The allometric relationships investigated here were length/length relationships. The different equations were estimated by pooling data collected from the three different sources. These relationships were statistically tested to assess whether there were significant sex and/or source effects in the parameters estimated. One equation was estimated for each allometric relationship. Each equation has the total length (Lt) as the independent variable and the dependent variables are the other eight variables, (Yn)[1]. To investigate a sex and source effects (differences between the three localities) in the allometric relationships, detailed models were fitted to the data collected. The test performed consisted in comparing the equality of the three localities regression coefficients and intercepts, involving the Fisher F distribution. To do this a series of nested models were used. The model fitted was:

$$Y = a_{sex + source} + b_{sex + source} * Lt + error,$$

where the intercept and the slope depend on sex and source. This model was compared with the model in which neither intercept nor slope depend on source and sex effects, $Y = a + b * Lt + error$. The Fobs was estimated as a quotient

(1) n represents the number of variables highlighted in figure 2. It varies between 2 and 9. The analysis performed was univariate, i. e., it only considers one dependent variable for each equation.

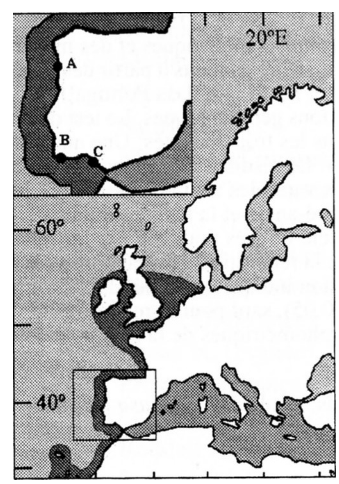

Fig. 1. - Map with the relative distribution of *P. lascaris*, according to Whitehead *et al*. (1986, modified). The different shades of grey represent the relative abundance. Enlarged map represents the Iberian Peninsula with the location of the three sampling districts (A: Porto area; B: Algarve; C: Gulf of Cadiz).

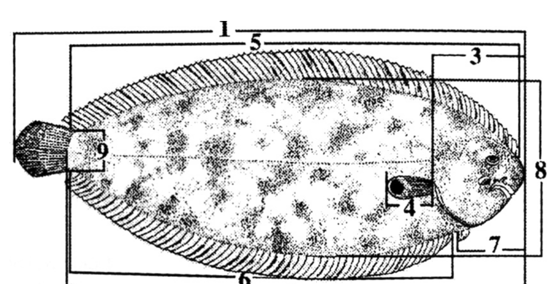

Fig. 2. - Illustration of a sand sole showing the measurements taken for morphometric studies; 1: total length; 2: standard length; 3: head length; 4: pectoral fin length; 5: dorsal fin length; 6: anal fin length; 7: pre-anal length; 8: maximum body height and 9: minimum body height (modified from Fisher *et al*., 1987).

Table I. - Summary of meristic counts obtained for *Pegusa lascaris*. The range represents the minimum - maximum by locality; n is the sample size.

Source	Fins	n	Median	Range
Algarve	Dorsal	100	82	73-92
	Pectoral	100	9	6-10
	Anal	99	66	60-76
Gulf of Cadiz	Dorsal	104	84	72-93
	Pectoral	105	8	7-9
	Anal	105	69	62-81
Porto	Dorsal	101	82	75-92
	Pectoral	100	8	6-12
	Anal	101	66	58-81

between the residual sum of squares and the degrees of freedom (Sokal and Rohlf, 1981; Zar, 1984).

RESULTS

Meristic counts

The sample size, median and ranges of the fin rays counted per fin by locality are presented in table I. Specimens from the Gulf of Cadiz showed the highest median for the dorsal and anal fins. The results were somewhat similar between the specimens captured in the Algarve and in the North of Portugal. However, the counts were significantly different between geographical areas ($p < 0.001$). The counts on the anal and dorsal fins did not show a significant departure from normality (K-S method, $p > 0.05$). Exception to this result was the counts on the pectoral fins in the three localities. This variable showed a distribution significantly different from the normal (K-S method, $p < 0.01$).

Morphometric measurements

Each morphometric character showed a straight-line relationship with total length (Fig. 3). The pectoral and pre-anal lengths and minimum height showed the lowest correlation with total length. The determination coefficient estimated for these relationships was low (≈ 0.60) and the correlation values less than 0.784. These variables showed high variability for the same total length.

When the nine morphometric measurements were pooled across localities the first component accounted for 84.5% of the variation in the data. All variables were highly scored with the first PC, except the pectoral and pre-anal lengths and minimum height (0.797, 0.825 and 0.794, respectively).

Clearly the first PC is essentially an average of the body measurements. The first PC can be written as: $PC1 = 0.99x_1 + 0.99x_2 + 0.96x_3 + 0.80x_4 + 0.98x_5 + 0.97x_6 + 0.83x_7 + 0.94x_8 + 0.80x_9$,

where x_i represents the morphometric variables and i varies

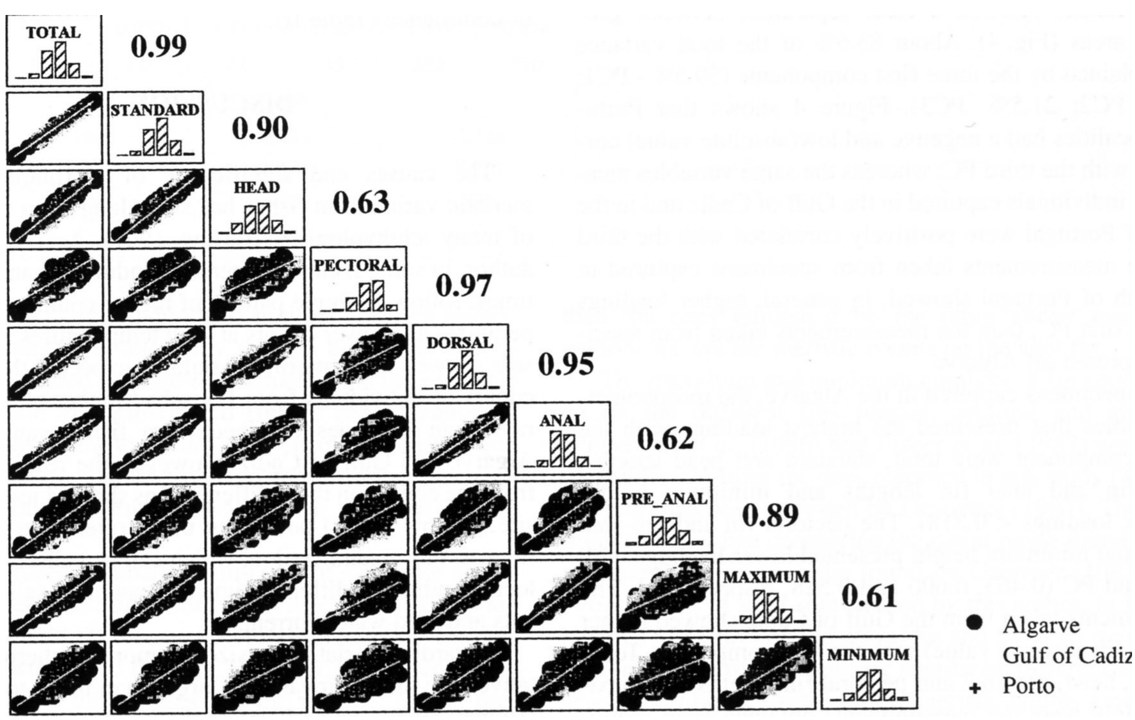

Fig. 3. - Matrix of plots showing the relationships between the nine-morphometric variables. The numbers on top of each variable represent the coefficient of determination, r^2, between each variable and total length.

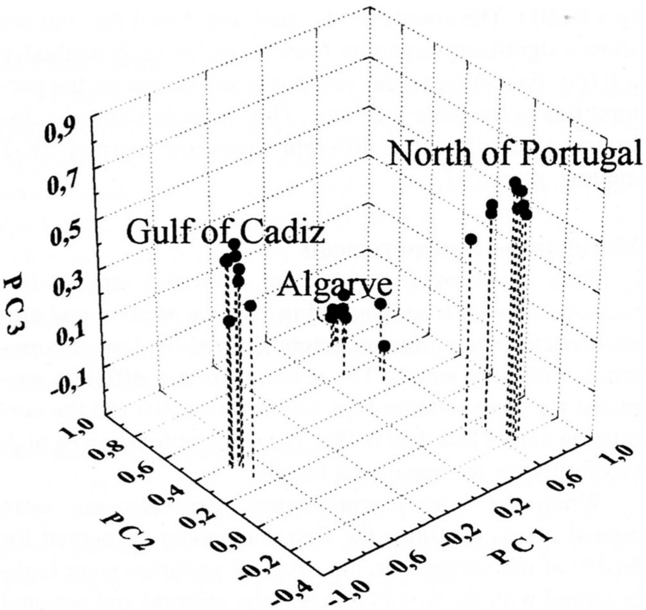

Fig. 4. - Morphometric measurements by locality plotted against the first three PC. The circles represent the localities.

from 1 to 9 corresponding to the measurements represented in figure 2.

The second situation considered was the fact that these measurements were taken from fishes collected in three different localities. The PCA of the measurements from the three localities showed a clear separation between geographic areas (Fig. 4). About 83.6% of the total variance was explained by the three first components (39.5% - PC1; 22.9% - PC2; 21.5% - PC3). Figure 4 shows that Portuguese localities had a negative and low(absolute value) correlation with the third PC; whereas the same variables measured in individuals captured in the Gulf of Cadiz and in the North of Portugal were positively correlated with the third PC. The measurements taken from specimens captured in the North of Portugal showed, in general, higher loadings with the first PC, than the measurements taken from specimens captured off Algarve.

For specimens captured in the Algarve, the morphometric variables that presented the highest loadings with the second component were total, standard and head lengths, dorsal fin and anal fin lengths and minimum height (0.761 < loadings < 0.818). The pectoral fin and pre-anal lengths and minimum height presented lower loadings with the second PC (0.463, 0.600 and 0.528, respectively). The measurements taken from the Gulf of Cadiz showed higher loadings (in absolute value) with the first component. Total, standard, head, pre-anal and pectoral fin lengths and maximum height were the measurements obtained from indivi-duals captured in the Gulf of Cadiz that showed higher loadings (in absolute value) with the first component (-0.705 < loadings < -0.756). The other three variables showed higher loadings with the first component but less than 0.70. The measurements taken from the North of Portugal did not show such a clear pattern. The total length showed higher loadings (0.712) with the third PC, whereas the head length showed higher loadings (0.745) with the first PC. The other seven variables showed higher loadings with the first and third PCs, but less than 0.70.

Allometric relationships

All morphometric variables showed a straight-line relationship with the total length (Fig. 3). However, in the pectoral and pre-anal lengths and minimum height variables the coefficient of determination was somewhat low, approximately 0.60. These variables showed high variation around the fitted line. However, the model fitted described all the relationships very well (except the three above mentioned cases), more than 89% of the variation in the dependent variable was accounted for by a linear prediction from total length.

The estimated regression parameters showed, in general a significant sex and/or geographic effect at 5% level of confidence (Table II), except in the relationship between total length and pectoral length. The regression coefficients estimated for this relationship did not show a sex or source effects ($p < 0.001$). The relationships between dorsal length/ total length and maximum length/total length were significantly different between sex and localities at 5% level of confidence (Table II).

DISCUSSION

The causes and significance of morphological and meristic variation in fishes has since long been the interest of many ichthyologists (Barlow, 1961). According to this author, in some fishes, temperature induced changes, sometimes, follow a simple pattern of higher counts at low temperatures and lower counts at high temperatures. If the sand sole showed this pattern, it would be expected that meristic counts of individuals from Porto had higher number of fin rays than the ones obtained from fishes caught in the Algarve and Gulf of Cadiz. However, the results obtained from the counts on three different fins showed just the opposite. Barlow (1961) points out many references for exceptions to this generalization, which can be caused by special local conditions, different time of spawning, salinity gradients and cold water currents.

Regarding variation in size the more northern representatives are almost invariably larger than those to the south (Hubbs, 1926). Since Porto is the most northern sampling area where it is a known fact that the seawater temperature is lower than in the Algarve and Gulf of Cadiz, it

Source		Algarve		Gulf of Cadiz		Porto	
Sex		Female	Male	Female	Male	Female	Male
L_2 = Standard	a	-0.300		-0.169		-0.110	
	b	1.035		1.009		1.004	
	n	534		94		258	
	r^2	0.992					
L_3 = Head	a	-1.414		-2.183		-1.794	
	b	0.942		1.069		1.004	
	n	257		99		529	
	r^2	0.917					
L_4 = Pectoral	a	-2.065					
	b	0.902					
	n	848					
	r^2	0.633					
L_5 = Dorsal	a	-0.172	-0.218	-0.567	-0.255	-0.227	-0.421
	b	1.006	1.012	1.076	1.018	1.014	1.048
	n	144	113	323	212	48	46
	r^2	0.974					
L_6 = Anal	a	-0.874		-0.186		-0.449	
	b	1.104		0.981		1.026	
	n	258		102		539	
	r^2	0.978					
L_7 = Pre-anal	a	-0.047		-1.884		-1.702	
	b	0.643		0.962		0.939	
	n	242		101		536	
	r^2	0.660					
L_8 = Maximum	a	-1.002	-0.578	-1.858	-1.434	-1.139	-0.715
	b	0.984	0.900	1.152	1.068	1.008	0.924
	n	145	113	47	45	322	210
	r^2	0.935					
L_9 = Minimum	a	-1.661		-3.011		-1.538	
	b	0.812		1.070		0.800	
	n	252		101		520	
	r^2	0.641					

Table II. - Parameters of the allometric equations estimated by adjusting nested models to the log-transformed data. Ln L_i = a + b * ln Lt, where L_i represents the different variables, Lt, a, b, i and r^2 stand for the total length, the intercept and slope of each regression equation, the number of cases and the coefficient of determination, respectively. Values that are not presented by sex and by source did not show sex or source effect in the parameters estimation at 5% level of confidence.

would be expected to find larger individuals in these northern waters. Still, the results from this study showed that larger indivi-duals were captured in Algarve. It appears that the sand sole is an exception to Barlow's and Hubb's generalization. It would be interesting to obtain data on morphometric and meristic variation for sand sole in more northern waters, e.g., from southern English waters and northern French waters.

The published numbers of fin-rays for sand sole according to Whitehead *et al*. (1986) and Fisher *et al*. (1987) are dorsal fin with 70-90 fin-rays, pectoral fin with 8-9 fin-rays and anal fin with 58-75 fin-rays. However, Desoutter (1997) made a study on this species and the meristic counts presented by this scientist (dorsal fin with 75-90 fin-rays, pectoral fin with 7-12 fin rays and anal fin with 54-73 fin-rays) are somewhat closer to this study (especially in Porto area) than the ones published by the other above mentioned authors, except the meristic counts on the anal fin.

The maximum and minimum numbers of fin rays counted on the different fins (dorsal, pectoral and anal) by Whitehead *et al*. (1986) and Fisher *et al*. (1987) are somewhat different from the ones recorded in this study (Table I) and from the ones recorded by Desoutter (1997). The same thing occurs when comparing the count range found in this study and the count range found by Gaertner (1982). The two varieties of sand sole studied by this author, in France, have 72 to 85 rays on the dorsal fin and 58 to 70 rays in the anal fin. Furthermore, there are significant differences at 5% level of confidence between the meristic counts among the three localities tested. However, the median values were similar between localities. These results are not surprising, since the distributions of each meristic variable by locality

were quite different. This result may indicate geographic differences between populations of the same species. It may also indicate that the meristic counts range is not a good 'parameter' for comparison purposes. Maybe in these cases the best parameter for comparison purposes would be the median or the mode of the meristic counts distribution.

The results obtained from the multivariate analyses of the morphometric measurements also showed a significant separation among localities. Considering that there was no 'research effect' (or that it is negligible), the population homogeneity studied by morphometric characters showed significant differences at 5% level of confidence among the three localities and suggested that the soles studied belong to more than a single population. This may lead to the conclusion that there are semi-independent, or independent subpopulations of the same species.

The results from this study on morphometric characters and meristic counts suggest that each of the areas included in this study is inhabited by a discrete group of sand sole. The sand sole from the north of Portugal are morphologically more similar to fish from the south of Portugal than are to fish from the Gulf of Cadiz. The observed differences are probably influenced by intra-specific factors and environment. It would be interesting to perform a study of the population structure of sand sole along the whole distribution area. Morphometric and meristic data should be collected in conjunction with tissue samples to be genetically analysed. Also, the use of sand sole's parasites as biological tags (similar to the study made by Hemmingsen *et al*. (1991) on cod) could be very useful to help separate the sand sole's hypothetical populations. More than one technique lends support to results. Therefore, the gathered information would contribute to a better understanding of the population of sand sole.

Acknowledgments. - We would like to acknowledge the European Commission for financing our project, allowing us the collection of very diverse and important biological data on five species of Soleidae (DG XIV 97/0083). We are grateful to M.P. Jiménez, I. Sobrino, Y. Vila, P.T. Santos, F. Ribeiro, S. Ramos and T. Gomes, our partners in the project, for collecting the data from the Gulf of Cadiz and North of Portugal. We wish to thank the Direcção Geral das Pescas e Aquicultura for, kindly, giving us commercial landing data on sand sole. We acknowledge the advice given by Dr J. Rohlf. To Dr. Martine Desoutter we would like to express our deepest thanks for the important contribution given to this manuscript.

REFERENCES

BARLOW G.W., 1961. - Causes and significance of morphological variation in fishes. *Syst. Zool*., 10: 105-117.

BEN-TUVIA A., 1990. - A taxonomic reappraisal of the Atlanto-Mediterranean soles *Solea solea*, *S. senegalensis* and *S. lascaris*. *J. Fish Biol.*, 36: 947-960.

DESOUTTER M., 1994. - Revision of the genera *Microchirus*, *Dicologlossa* and *Vanstraelenia* (Pleuronectiformes, Soleidae). *Cybium*, 18(3): 215-249.

DESOUTTER M., 1997. - Révision systématique des genres de la famille des Soleidae présents sur les côtes de l'est-atlantique et de la Méditerranée. 182 p. Thesis. Paris: Muséum national d'histoire naturelle.

FISHER W., SCHNEIDER M. & M.-L. BAUCHOT, 1987. -Fiches FAO d'identification des espèces pour les besoins de la pêche. Méditerranée et Mer Noire (Zone de Pêche 37). Vol. 11-Vertébrés: 1325-1342. Rome: FAO.

GAERTNER D., 1982. - Analyse biométrique de *Solea lascaris* (Risso, 1810) en baie de Douarnenez (Finistère). *Cybium,* 36(1): 15-33.

HEMMINGSEN W., LOMBARDO I. & K. MACKENZIE, 1991. - Parasites as biological tags for Cod, *Gadus morhua* L., in northern Norway: A pilot study. *Fish. Res*., 12: 365-373.

HUBBS C.L., 1926. - The structural consequences of modifications of the developmental rate in fishes, considered in reference to certain problems of evolution. *Am. Nat*., 60: 57-81.

MANLY B., 1994. - Multivariate Statistical Methods: A primer. pp. 59-71. Chapman and Hall.

SCHAEFER K.M., 1989. - Morphometric analysis of yellowfin Tuna *Thunnus albacares* from the eastern Pacific Ocean. *Fish. Bull*., 89: 289-297.

SOKAL R.R. & F.J. ROHLF, 1981. - Biometry. The Principals and Practice of Statistics in biological Research. 859 p. New York, 2nd edit.: W.H. Freeman and Company.

WHITEHEAD P.J.P., BAUCHOT M.-L., HUREAU J.-C., NIELSEN J. & E. TORTONESE (eds), 1986. - Fishes of the North-eastern Atlantic and the Mediterranean. UNESCO.

ZAR J.J., 1984. - Biostatistical Analyses. 718 p. London: Prentice-Hall.

Reçu le 21 septembre 2000.
Accepté pour publication le 16 octobre 2001.